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GB 2161951 A WO 96/12987 A1

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(54) Abstract Title
Dye doped liquid crystal device

(57) A liquid crystal device comprises a dye doped nematic liquid crystal material in a homeotropic orientation in which a permanent diffraction pattern is written at an angle to the director axis. Liquid crystal material is contained between two transparent plates. A single alignment layer is applied to one of the transparent plates in order to generate the homeotropic alignment. The efficiency of the diffraction by the pattern in the liquid crystal layer can be controlled by the application of an AC electric field across the liquid crystal material and the liquid crystal panel can be tuned by heating the liquid crystal material to change the refractive index.

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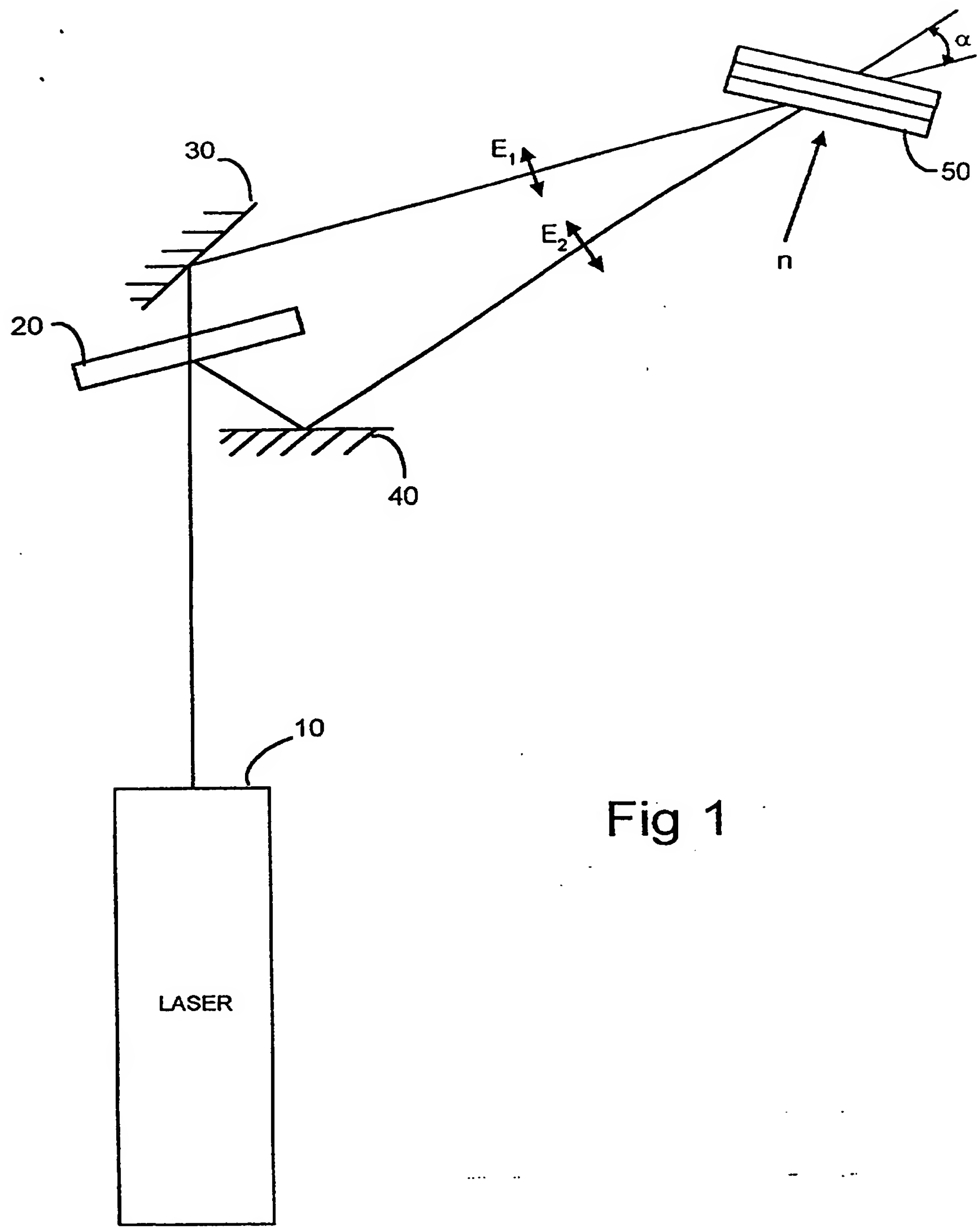


Fig 1

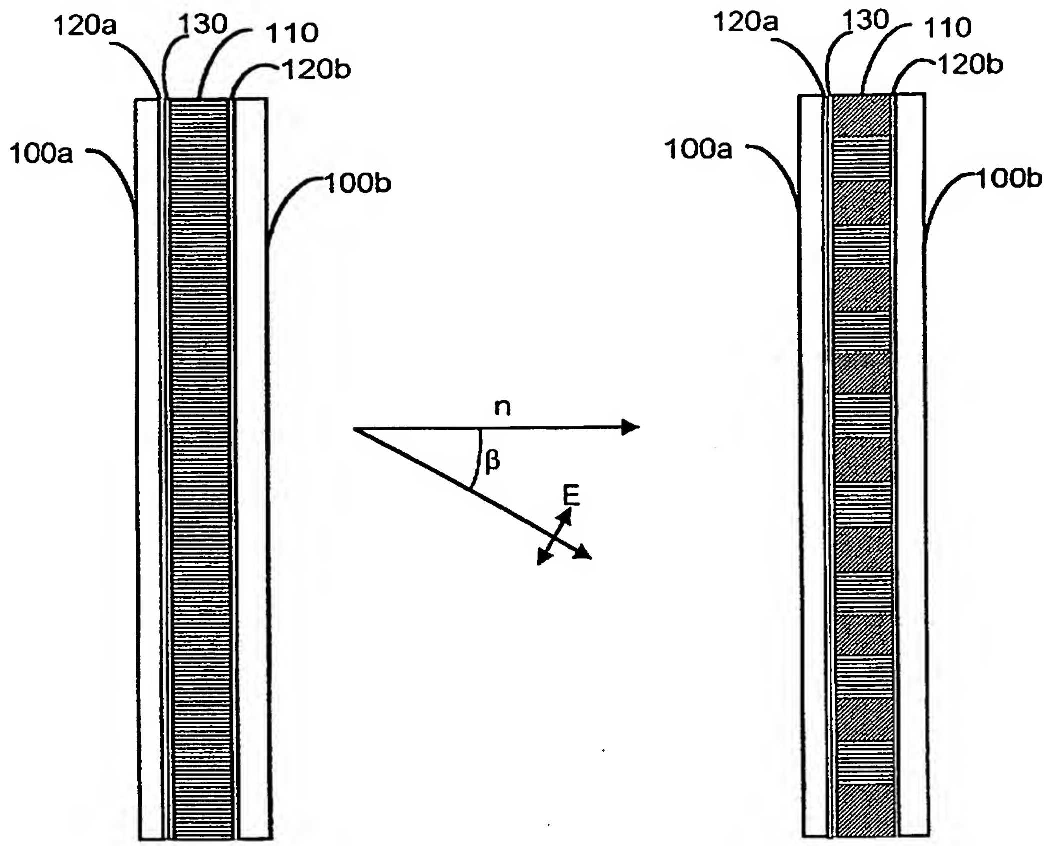


Fig 2a

Fig 2b

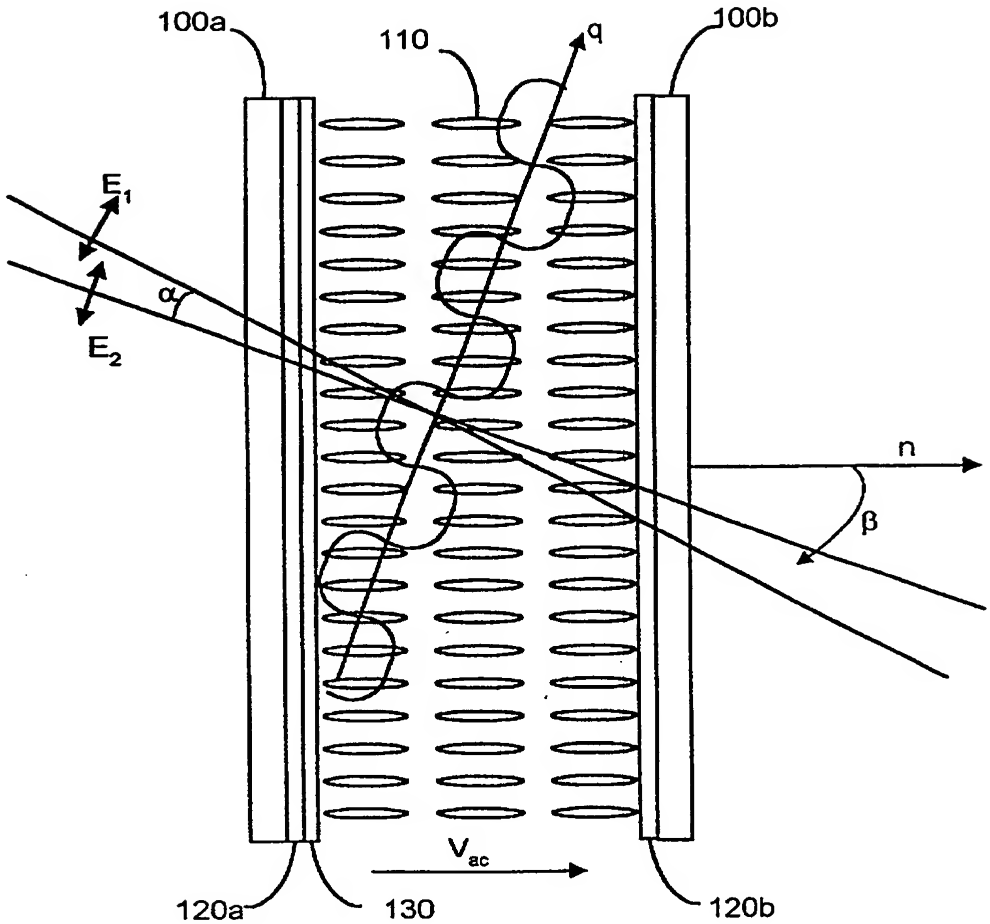


Fig 3

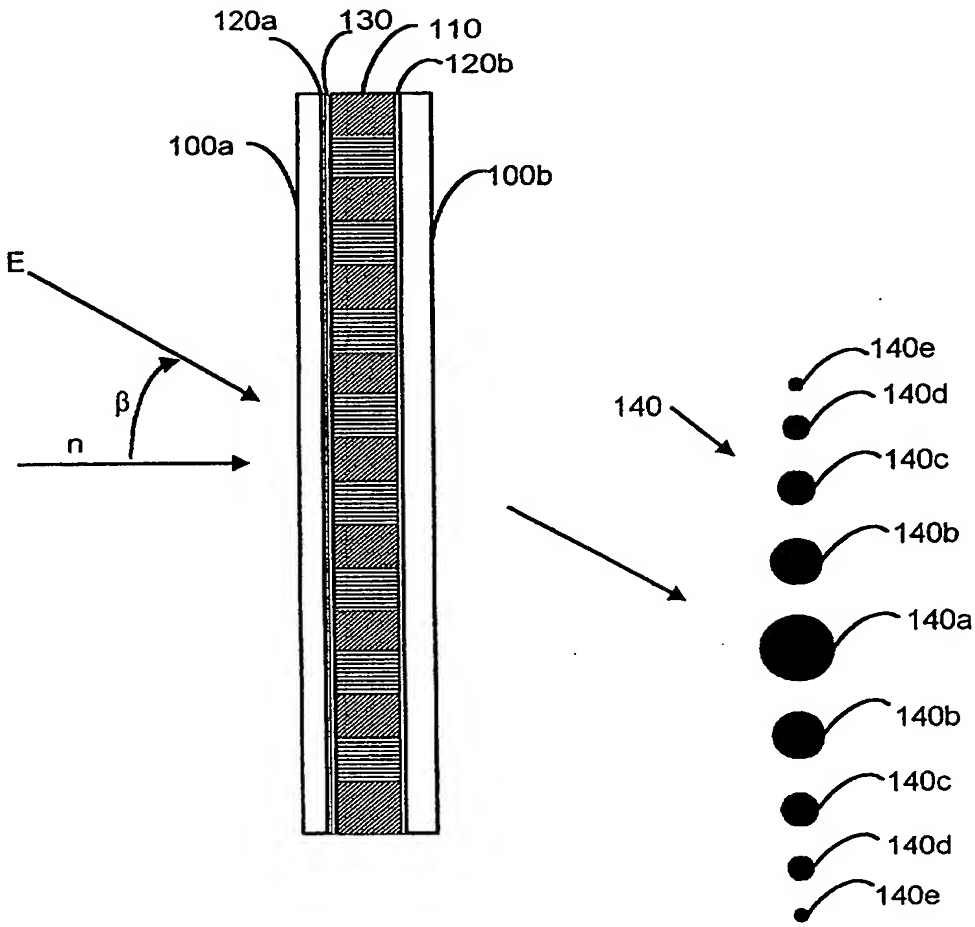

120a
130
110
120b
100a
100b
E
β
n
140
140e
140d
140c
140b
140a
140b
140c
140d
140e

Fig 4

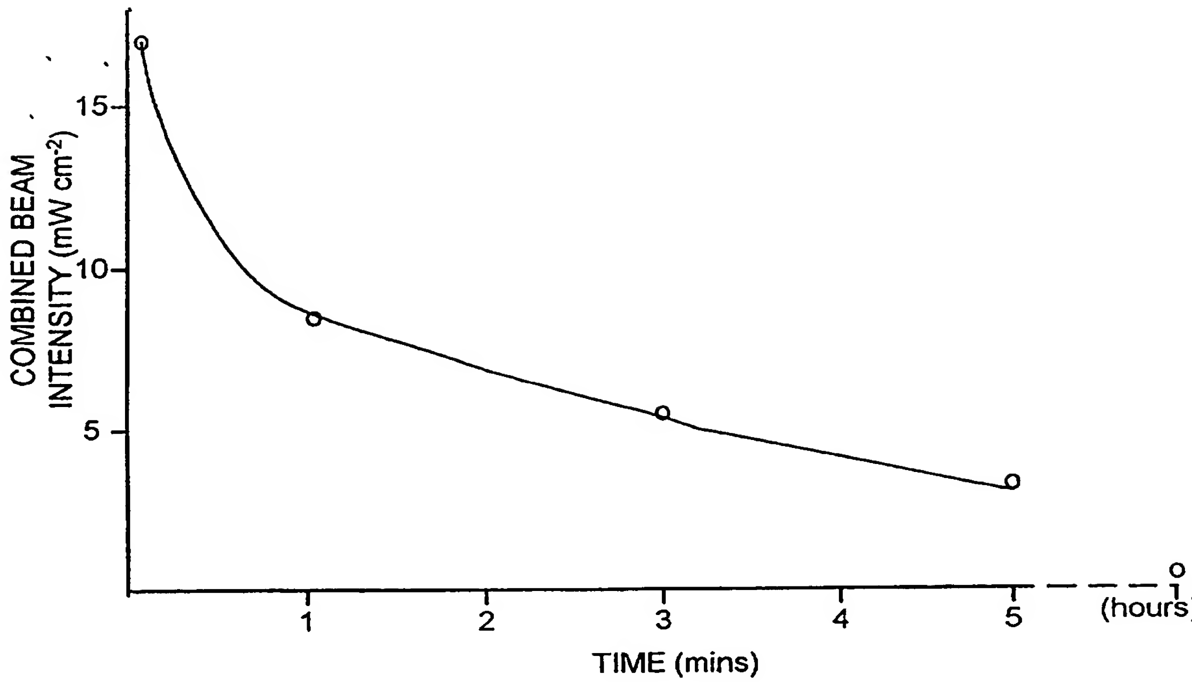
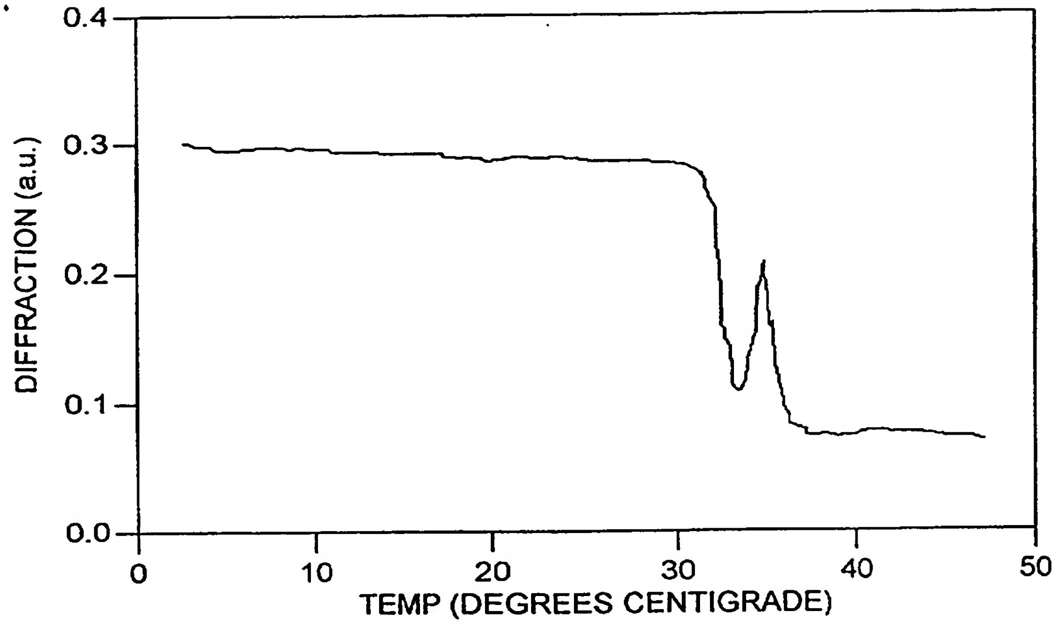

15
10
5
COMBINED BEAM INTENSITY (mW cm-2)
1
2
3
4
5
1
(hours)
TIME (mins)

Fig 5



0.4
0.3
0.2
0.1
0.0
DIFFRACTION (a.u.)
0
10
20
30
40
50
TEMP (DEGREES CENTIGRADE)

Fig 6

Peak intensity of diffracted signal versus frequency of external AC field

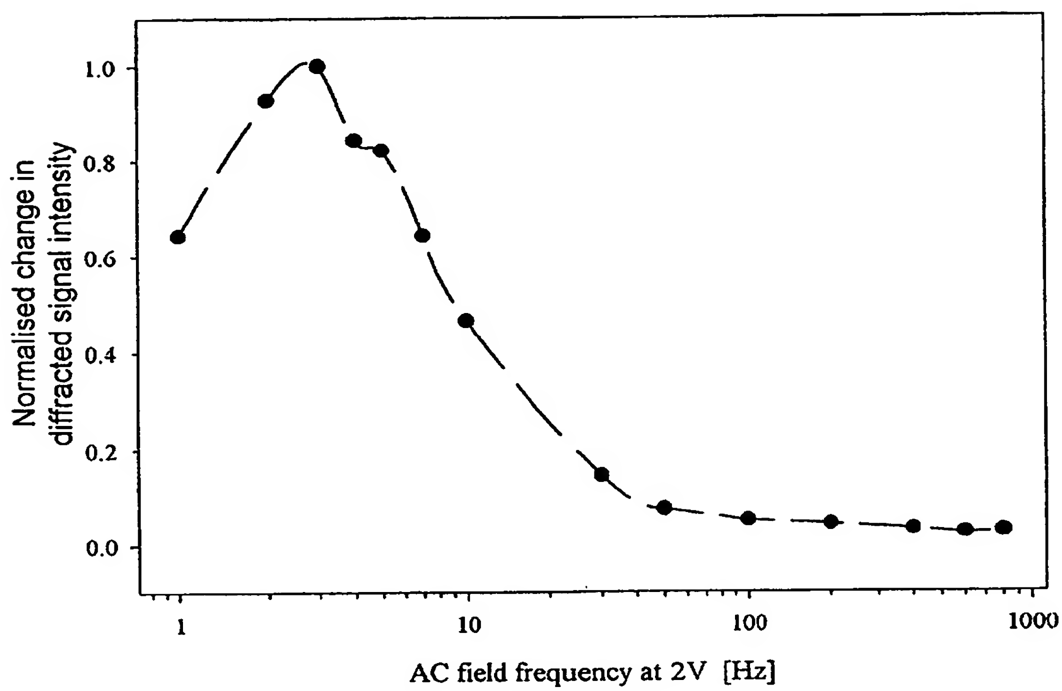


Fig 7

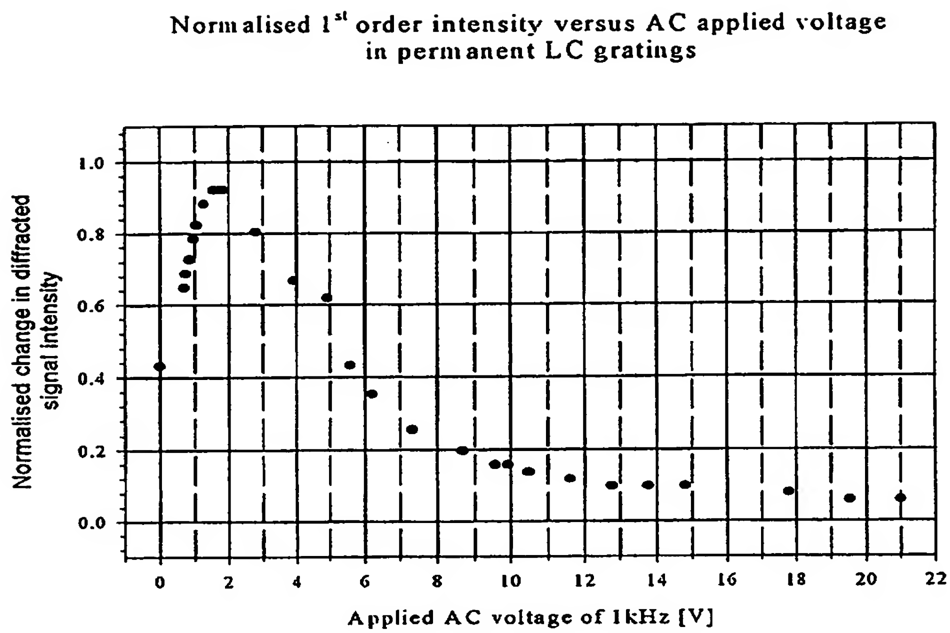

Normalised 1st order intensity versus AC applied voltage
in permanent LC gratings
Normalised change in diffracted
signal intensity
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
14
16
18
20
22
Applied AC voltage of 1kHz [V]

Fig 8

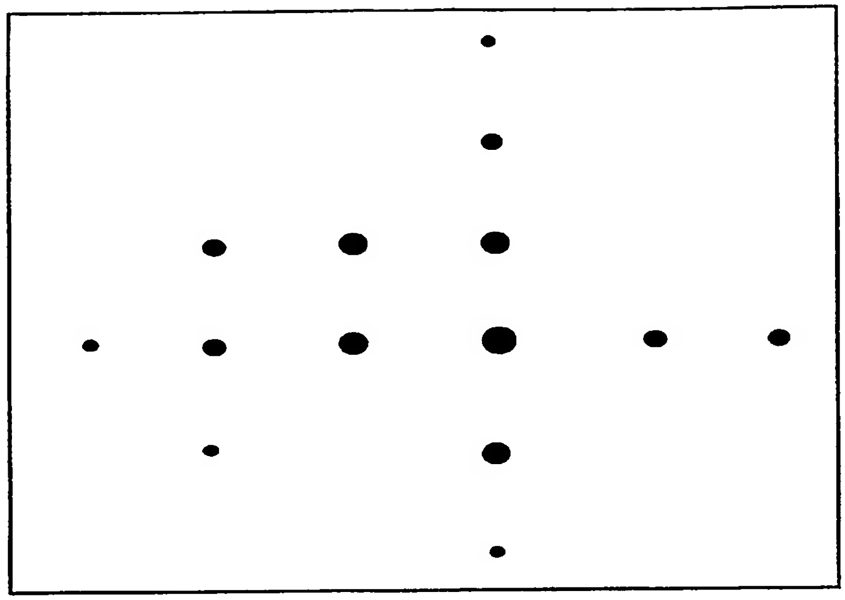


Fig 9

LIQUID CRYSTAL DEVICE, METHOD OF MANUFACTURING A LIQUID CRYSTAL DEVICE AND METHOD OF OPERATING A LIQUID CRYSTAL DEVICE

The present invention generally relates to a liquid crystal device in which a pattern is formed in the liquid crystal by selective alignment.

Liquid crystals form an important part of technology today, in particular in areas such as optoelectronics and optical materials. They have found numerous applications in, for example, computer displays and light modulators. However, in recent years the possibility of using light instead of electric fields to modify the parameters has led to the discovery that exposing doped liquid crystals to a spatial light intensity profile results in strong patterns being written in the liquid crystal material.

In optical materials, such as photorefractives, properties like refractive index and absorption can be modulated by laser light and thus various patterns can be recorded and a wide variety of interesting and non-linear effects observed. However, conventional photorefractive materials, such as ferroelectric crystals, have found only limited practical applications so far, in spite of their large efficiencies. They tend to be difficult to interface with optical fibres because of their bulk size,

solid state and high refractive index. Therefore, the discovery of the process of writing photorefractive like gratings in liquid crystals has opened new possibilities for the application of liquid crystals in, for example, image and beam processing and optical telecommunications to perform different functions on light. The new photosensitive doped liquid crystals are not only more versatile and efficient, but also a great deal cheaper. This makes them attractive candidates to replace the additional materials like $BaTiO_3$ or $LiNbO_3$.

In the prior art, patterns have been created in liquid crystals which have been doped with Fullerene C_{60}. Such a technique is disclosed in a paper by I C Khoo entitled "Optical DC Field Induced Space Charge Fields and Photorefractive Like Holographic Grating Formation in Nematic Liquid Crystals" (Mol. Cryst. Liq. Cryst, 1996, Vol. 282, pp 33-66). The arrangement for recording the grating involved exposing the liquid crystal sample between two glass plates to an interference pattern created by intersecting two laser beams at an angle. In this technique a DC field assisted the formation of the grating. The grating which was created persists indefinitely but can be turned off by applying a high AC field at 94 volts and 200 Hz. When the field is turned off the grating recovers.

Another technique which is disclosed in the prior art for creating gratings uses dye-doped nematic liquid crystals. This prior art technique is disclosed in papers by E V Rudenko *et al* (Mol. Cryst. Liq. Cryst. Science and Technology A, Vol. 282, pp 125-137), I C Khoo (IEEE J. Quant. Electron., Vol. 32, No. 3, March 1996, pp 525-534), I C Khoo *et al* (Opt. Lett. Vol. 22, 1997, pp 1229-1231), G Cipparrone *et al* (Opt. Letts. Vol. 23, 1998, pp 1505-1507), and O Francescangeli *et al* (Phys. Rev. Lett. Vol. 82, 1999, pp 1855-1858). This prior art technique generates strong photorefractive like patterns in dye doped nematic liquid crystals. In the papers by E V Rudenko and I C Khoo mentioned above, the photorefractive like patterns were an order of magnitude stronger ($\Delta n \approx 7 \times 10^{-3}$) than in the best conventional photorefractive materials. In the prior art, the gratings generated were both dynamic i.e. they decayed after the writing beams was switched off, or permanent. The dynamic gratings can be erased and rewritten in real time.

There is a need for improved optical materials for use in optical storage and telecommunications. For storage applications, inexpensive media suitable for permanent recordings, high storage capacity and high sensitivity are particularly sought after. For optical

telecommunications applications, compatible materials, whose properties can be easily controlled are needed for use as switches, filters and back reflectors for example.

Although permanent gratings have been identified in the prior art, the ability to tune these patterns to ensure their wide spread applications has not been disclosed. Further, the prior art has not disclosed the possibility of tuning the efficiency of these patterns.

It is an object of the present invention to provide a liquid crystal device which overcomes the limitations in the prior art.

In particular, it is an object of one aspect of the present invention to overcome the limitations of the prior art and provide a liquid crystal device which is tunable.

It is an object of another aspect of the present invention to provide a liquid crystal device which can have its pattern efficiency controlled.

In accordance with the first aspect of the present invention there is disclosed a method of manufacturing a liquid crystal device in which a permanent pattern can be created in a dye doped liquid crystal material. The dye doped liquid crystal material is contained between two transparent plates. An inner surface of one of the transparent plates is coated with an alignment material

such that when the liquid crystal material is placed between the transparent plates, a liquid crystal layer having a homeotropic alignment is formed. In such an arrangement the liquid crystals are aligned across the gap between the transparent plates. The liquid crystal panel is then exposed to a light beam which has a spatial intensity pattern. The light beam is projected at an angle to perpendicular to the glass plates in order to selectively rotate the direction of alignment of the liquid crystals within the liquid crystal layer.

Thus in the technique of the present invention only one alignment layer need be used.

The pattern generated within the liquid crystal material can be any form of pattern but most conveniently comprises a grating pattern generated by an interference pattern in a liquid crystal layer. Conveniently, interference pattern can be generated by the interference between two optical beams within the liquid crystal layer.

The pattern generated within the liquid crystal layer can be one or two dimensional. A two dimensional pattern can be created either by a single step or by sequentially exposing the liquid crystal layer to a plurality of spatial light intensity patterns e.g. one dimensional patterns rotated about an axis or scanned

dimensional patterns rotated about an axis or scanned across the liquid crystal panel. It is also possible to generate a three dimensional pattern by providing sandwiched layers of liquid crystal material each with a two dimensional pattern arranged therein. Each of the liquid crystal layers has to be kept separate by a suitable barrier means so that the two dimensional patterns in the separate liquid crystal layers do not interfere with one another.

Thus in accordance with one aspect, the present invention provides a liquid crystal panel in which a multidimensional pattern is written into a liquid crystal layer.

The ability to write sequentially more than one pattern into a liquid crystal layer is facilitated by the fact that the pattern generated within the liquid crystal layer is permanent. The pattern cannot be removed either by applying an electric or optic field, or by heating. Even if the crystal material is heated above the phase transition point, when the liquid crystal is cooled below the phase transition point, the pattern returns.

Thus an aspect of the present invention provides a liquid crystal panel in which is written a permanent grating which can be switched off by heating above the phase transition point of the liquid crystal, and

switched back on again by cooling to below the phase transition point.

The liquid crystal preferably comprises a nematic liquid crystal since it is the simplest type of liquid crystal with only one dimensional order of molecules. When the liquid crystal is applied between the transparent e.g. glass plates, the direction of average orientation of the longer axis of the molecule, termed the director axis, is aligned across the gap between the glass plates in the homeotropic orientation. The present invention is not however limited to nematic liquid crystals or to homeotropic alignment, and the present invention can be applied to any liquid crystal which allows for selective orientation of the liquid crystals within the liquid crystal region by the selective application of light.

The present invention preferably uses dye as the doping material and the dye used will depend upon the wavelength of the light used to generate the interference pattern. Clearly the interference pattern will need to interact with the dye in order to generate the pattern within the liquid crystal material. Thus the absorption properties of the dye must be appropriately selected or matched to the wavelength of light used.

In a preferred embodiment of the present invention, a particularly high level of dye doping was used and this resulted in a lower intensity level required in order to generate a pattern within the liquid crystal.

One aspect to the present invention provides a method of operating a liquid crystal panel in which the efficiency with which the liquid crystal generates the light pattern is increased by applying an AC field across the liquid crystal layer. The voltage required can be quite low and less than 15 volts. Preferably 10 volts or even 5 volts can be used. The frequency of the AC field applied can be any frequency. The efficiency of the grating will however follow the AC component of the field applied and thus the effects can be used to modulate an optical signal, or a high frequency could be chosen which is well above the frequency of interest to reduce its effect in the output.

A further aspect to the present invention provides a liquid crystal device in which the frequency of operations of the device can be tuned by changing the temperature of the liquid crystal material within the device to change the refractive index of the liquid crystal material. In this way when a grating pattern is created within the liquid crystal, by changing the

refractive index, the frequency of operation of the grating can be tuned.

Any form of heating technique can be used for the liquid crystal material. Conveniently, pulses of high intensity laser light can be used.

Embodiments to the present invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of the arrangement for creating a pattern within a liquid crystal panel;

Figure 2a schematically illustrates the homeotropic alignment of the liquid crystals before the pattern is created;

Figure 2b schematically illustrates the alignment of the liquid crystals after the pattern has been created;

Figure 3 is a diagram illustrating the interacting fields in the liquid crystal panel;

Figure 4 illustrates the illumination of the liquid panel with a probe beam to generate a diffraction pattern;

Figure 5 illustrates the relationship between time and intensity of the laser beams for the creation of a permanent grating in the liquid crystal layer;

Figure 6 is a diagram illustrating the affect of increase in the temperature on the diffraction efficiency (in an arbitrary units) for the liquid crystal material;

Figure 7 is a graph of the normalised change in diffraction signal intensity versus AC field frequency at 2 volts;

Figure 8 is a graph of the normalised change in diffracted signal intensity verses applied AC voltage at 1 kHz; and

Figure 9 is a diagram of a two dimensional diffraction pattern achieved by the sequential writing of orthogonal gratings in the liquid crystal layer.

Referring now to Figure 1, generation of a grating pattern in a liquid crystal panel will now be described.

A laser 10 generates a light beam at 488 nm. The beam passes through a beam splitter 20 to generate two separate beams which are reflected off respective mirrors 30 and 40 to generate two beams which cross within the liquid crystal panel 50 at an angle α. The two beams with fields E_1 and E_2 interfere within the liquid crystal layer to generate an interference pattern. This interference pattern is generated at an angle to the director axis n which indicates the homeotropic

orientation of the liquid crystal before the writing of the pattern.

Figure 2a illustrates the construction of the liquid crystal pattern in more detail. The liquid crystal material 110 was fabricated using a mixture of nematic liquid crystal K15 (Pentyl-Cyano-Biphenyl) doped with the dye, Methyl red. The concentration of the dye was higher than used in the prior art, to get a low transmission of light in the sample. At the laser wave length at 488 nm, the transmission was only 10% for the 12 μm thick sample. A uniform distribution of the dye droplets was controlled by applying ultrasonic vibrations. The liquid crystal panel comprises two parallel glass plates 100a and 100b which have transparent ITO (Indium Tin Oxide) electrodes applied thereto to allow the application of the electric fields across the liquid crystal layer 110. Also on one of the glass plates an alignment layer 130 was provided by a lecithin solution. In this way when the liquid crystal material 110 is applied to the region between the glass plates 100a and 100b, a homeotropic alignment of liquid crystal molecules is achieved as illustrated in Figure 2a.

As illustrated in Figure 2b, the application of the visible radiation 488 nm by the CWR laser 10 generates a grating pattern within the liquid crystal material 110

which comprises variations in the alignment of the liquid crystals to the homeotropic direction.

The grating pattern generated within the liquid crystal 110 has a grating spacing of 11 μm. The angle of the electric field E to the director axis n, β is 45 degrees. The grating spacing generated within the liquid crystal material 110 will depend upon the wavelength of the light used (which will be chosen dependent upon the absorption properties of the dye used) and the angle β.

Figure 3 illustrates the direction of interacting fields in more detail.

The two beams E_1 and E_2 interact at an angle α within the liquid crystal material 110. The two beams E_1 and E_2 impinge on the liquid crystal panel at an angle β to the director axis n. The interference of the beams E_1 and E_2 within the liquid crystal generates a grating of wave vector q. An AC electric field E_{ac} can be applied across the liquid crystal material 110 via the ITO electrodes 120a and 120b as will be described in more detail hereinafter.

The beams E_1 and E_2 will linearly polarised so that the polarisation is not orthogonal to the director axis n. This ensures interaction of the beams E_1 and E_2 within the liquid crystal material to form a grating

pattern. In order to read the recorded diffraction pattern, as illustrated in Figure 4, a probe beam E is used to illuminate the pattern in order to generate a diffraction pattern 140. The probe beam E is projected at the same angle β to the director axis as used in the writing of the grating pattern. As can be seen in the diffraction pattern, in addition to the zero order pattern 140a, several diffraction orders can be observed i.e. first order 140b, second order 140c, third order 140d and fourth order 140e.

The conditions for generating and controlling the pattern will now be described.

Table 1 below illustrates the total intensity to the two rising beams and the time required to generate permanent grating in the liquid crystal panel.

TABLE 1

Total Intensity of two writing beams	Time required to write a permanent grating
405 $\mu W/cm^2$	Several hours
3.22 mW/cm^2	5 minutes
5.63 mW/cm^2	3 minutes
8.47 mW/cm^2	1 minute
16.9 mW/cm^2	3 seconds

This is also illustrated graphically in Figure 5.

It can be seen from this that a certain amount of energy is required in order to generate the permanent grating. If a high energy beam is used, this is required for less time in order to impart the necessary energy in the liquid crystal layer. If a lower intensity beam is used, then it is required for a longer time period. If the intensity of the beam is too high, this can cause thermal damage within the liquid crystal and thus either no grating pattern is observed or a damaged one. It is believed that the formation of a permanent grating is achieved by a thermal effect causing a chemical reaction due to the localised heating caused by the absorption of the incident beam by the dye in the liquid crystal mixture. It thus can be seen that it is possible to write a permanent grating with a low intensity although the time taken to write the pattern can be long.

If the intensity of the beam is too low, or the length of time taken for writing the beam is too low, then a transient diffraction pattern is created which will decay when the writing beams E_1 and E_2 are turned off.

Figure 6 is a graph illustrating the diffraction strength of the liquid crystal material verses temperature. The diffraction is given in arbitrary units. It can be seen that at a temperature below about

32°C, there is a high level of diffraction since the nematic liquid crystal is in the nematic phase. Above this temperature the liquid crystal material undergoes a phase transition and at around 35°C the liquid crystal material enters the isotropic phase and the diffraction efficiency is low. It can thus be seen from this graph that by heating the liquid crystal material, the diffraction effects of the pattern can be switched off. This process can be reversed by cooling where upon the diffraction efficiency is almost completely regained very quickly. The full diffraction efficiency is only regained after some time as the liquid crystal relaxes. Thus the permanent liquid crystal cannot be destroyed by heating and cooling. The heating and cooling cycle can be used as a method of switching off and on the liquid crystal diffraction pattern.

Because of the stability of the grating pattern permanently generated in the liquid crystal layer, it can be seen that it is possible to operate within the nematic phase and vary the temperature up to 32°C. This has the benefit that a change in temperature of the liquid crystal material changes the refractive index. A change in refractive index changes the frequency characteristics of the grating pattern generated within the liquid

crystal material. Thus in this way it is possible to tune the pattern.

Figure 7 is a graph showing the normalised change in diffracted signal intensity for the applied AC field frequency at a voltage of 2 volts. It can be seen from this that there is a peak in diffraction efficiency at around 3 Hz. Thus the application of a low voltage AC field causes an increased diffraction intensity which tends to follow the applied voltage. It can be postulated that this peak is due to the inertial characteristics of the liquid crystals. At low frequency, the crystals are being pulled slowly into alignment between the electrodes, where as at a high frequency the liquid crystals are unable to respond quickly enough to the rapidly changing electric field.

Figure 8 is a graph showing the normalised change in diffracted signal intensity for the applied AC voltage at 1 kHz. It can be seen from Figure 8 that at an AC frequency of 1 kHz, a low voltage of around 2 volts generates the largest increase in diffraction efficiency. It can thus be postulated from this that a low field is necessary to provide the low level of perturbations of the liquid crystals to achieve the increased diffraction efficiency.

In the embodiment described hereinabove, the diffraction grating generated within the liquid crystal material is one dimensional since the interference pattern (interference fringes) generated within the liquid crystal material is one dimensional (it has a periodicity only in one direction). However, since the grating pattern generated is permanent, it is possible to repeatedly write one dimensional grating patterns into the liquid crystal material.

Figure 9 is a diagram of the interference pattern generated by the writing of two orthogonal gratings in the liquid crystal material. When laser beams are used to write two orthogonal gratings into the liquid crystal material, the diffraction pattern can be generated by using a probe beam at the same combined angle i.e. solid angle of 45 degrees to the director axis with respect to the two orthogonal axis. It should be noted that the diffraction pattern of Figure 9 is not symmetric since the laser beams used to generate these diffraction patterns are not truly one dimensional but comprise a two dimensional area or spot.

Although the diffraction pattern illustrated in Figure 9 is two dimensional, it is only created along two axis. It is also possible to generate an axially symmetric diffraction pattern having diffraction patterns

rotated about a point by rotating the angle β about the director axis.

Instead of generating a two dimensional pattern by sequentially writing one dimensional gratings, it is also possible to generate a two dimensional diffraction pattern within the liquid crystal material in one step to thereby generate the two dimensional grating. For example, a Michelson interferometer can be used to generate a beam formed from two beams on the same axis and having different path lengths to thereby generate circular diffraction patterns (rings).

It is also possible to extend this idea to a three dimensional pattern by laminating two dimensional patterns. Each two dimensional pattern generated within a liquid crystal layer must be kept separate from each other by a boundary layer.

A liquid crystal device which is adaptive and controllable can be interfaced with fibres and can provide enormous potential for applications in optical telecommunications devices. Dynamically addressable and wavelength selective fibre components are currently missing from the optoelectronic toolbox. In particular, wavelength selective fibre components are currently the most sought after devices for applications in optical signal processing and wave length-division multiplexing

technology. The need for evermore efficient telecommunications components (such as filters, amplifiers or modulators) is driven by the demand for higher speed and capacity of data transmission in optical networks, and requires the development and ideas to be implemented in these devices. Existing technologies, based on integrated optics and semiconductor optoelectronics are being heavily exploited. Adaptive wavelength control in telecommunications fibres is of particularly interest and importance. In dense wave length division multiplexing systems, tunability of individual wavelengths is critical to ensure channel balancing, selective tapping, tuning or adjustment to compensate for signal strengths. The present invention allows tunability of individual grating diffraction deficiencies to intelligent electrical control. This technique will allow the possibility of achieving tunable channel balancing in erbium-doped fibre amplifiers. Further, liquid crystals with permanent but adaptive patterns when used as photosensitive overlays in geometry such as side-polished fibre architectures can achieve a flexible control of light transmission through the fibre. In this architecture, the fibre cladding is removed by side polishing to create a "window" into the fibre core to access the guided light. If an overlay is placed over

this window, coupling occurs between a side polished single-mode fibre, and a planar thin film overlay. Serial tunable liquid crystal overlays placed on an exposed core of the side polished fibre can be engineered and yield reconfigurable wavelength converters for wavelength division multiplexing.

Two dimensional patterns can be particularly useful for applications as image and information processing elements. The processing of optical images or matrix data as two dimensional slices is much more efficient than the single bit-by-bit reading from one dimensional patterns.

The present invention is also applicable to holographic optical components and optical storage.

Thus the present invention can provide an optical element for use in optical storage, holography, or telecommunications, which incorporates the liquid crystal device as hereinabove described.

Although the present invention has been described hereinabove with reference to the specific embodiments, it will be apparent to the skilled person in the art that the present invention is not limited to the specific embodiments and modifications are possible which lie within the spirit and scope of the present invention.

CLAIMS:

1. Liquid crystal apparatus comprising:

a liquid crystal layer arranged between two transparent members, each transparent members having an electrode layer thereon, said liquid crystal layer comprising a dye doped liquid crystal material having a grating pattern formed therein by an optical interferometric writing technique; and

means for applying an AC electric voltage to said electrode layers to generate an AC field across the liquid crystal layer to increase the diffraction efficiency of the grating pattern.

2. Liquid crystal apparatus comprising:

a liquid crystal layer arranged between two transparent members, said liquid crystal layer comprising a dye doped liquid crystal material having a pattern formed therein by an optical writing technique; and

means for selectively heating said liquid crystal layer to change the refractive index thereof to thereby change the frequency response of the liquid crystal layer.

3. A method of manufacturing a liquid crystal panel having a permanent pattern, the method comprising:

applying an alignment layer to one of a pair of transparent plates, each transparent plate having an electrode layer applied to a surface thereof, said alignment layer being applied to the electrode layer of one of said transparent plates;

arranging said transparent plates in parallel to form a region to hold liquid crystal material;

applying a dye doped liquid crystal material to the region between said transparent plates to form a homeotropic liquid crystal layer having a director axis normal to said transparent plates; and

exposing the liquid crystal layer to light having a spatial intensity pattern at an angle to the director axis and a polarisation component which is not orthogonal to said director axis.

4. A method according to claim 3, wherein the exposing step comprises exposing said liquid crystal layer to an interference pattern to generate a grating pattern in said liquid crystal layer.

5. A method according to claim 3 or claim 4, wherein said pattern is one dimensional.

6. A method according to claim 3 or claim 4, wherein

said pattern is two dimensional.

7. A method according to claim 6, wherein said two dimensional pattern is created by sequentially exposing said liquid crystal layer to a plurality of spatial light intensity patterns.

8. A method according claim 3 or claim 4, wherein said liquid crystal region is formed of a plurality of separate layers between said transparent plates and separated by transparent barrier means, and a three dimensional pattern is created in the liquid crystal region by exposing each of the separate layers to light having a respective said spatial light intensity pattern.

9. A method according to any one of claims 3 to 8, wherein said dye doped liquid crystal comprises a nematic liquid crystal material.

10. A method according to claim 9, wherein the liquid crystal is doped with methyl red.

11. A method according to any one of claims 3 to 10,

wherein said dye doped liquid crystal has a doping level of at least 1% by weight.

12. A method according to claim 11, wherein said dye doped liquid crystal has a doping level sufficient to reduce the transmission of light to below 20%.

13. A method according to claim 12, wherein said dye doped liquid crystal has a doping level sufficient to reduce the transmission of light to below 15%.

14. A method according to claim 12, wherein said dye doped liquid crystal has a doping level sufficient to reduce the transmission of light to below 10%.

15. A method according to any one of claims 3 to 14, wherein said dye used for doping and the wavelength of the light used for exposing are selected dependent upon one another.

16. A method according to any one of claims 3 to 15, including the step of applying ultrasonic vibrations to the dye doped liquid crystal to uniformly distribute the dye.

17. A method according to any one of claims 3 to 16, wherein no DC voltage is applied across said electrode layers.

18. A method according to any one of claims 3 to 17, wherein said light used in the exposing step comprises coherent light.

19. A method of operating a liquid crystal device having a homeotropic dye doped liquid crystal region with a pattern formed therein, the pattern defining different alignment regions in the liquid crystal, the method comprising:

illuminating the pattern with a beam of light to interact with the pattern to generate a light pattern; and

applying an AC field across said liquid crystal region to increase the efficiency with which the liquid crystal generates the light pattern.

20. A method according to claim 19, wherein said pattern in the liquid crystal region is a grating pattern generated for reading at an angle to the director axis, said beam of light is applied at said angle to generate a diffraction pattern, and said applied AC field

increases the diffraction efficiency of the grating pattern.

21. A method according to claim 19 or claim 20, wherein said liquid crystal panel has been manufactured using the method of any one of claims 1 to 16.

22. A method according to any one of claims 19 to 21, wherein the voltage of the AC field is less than 15 volts.

23. A method according to any one of claims 19 to 21, wherein the voltage of the AC field is less than 10 volts.

24. A method according to any one of claims 19 to 21, wherein the voltage of the AC field is less than 5 volts.

25. A method of changing the frequency of operation of a liquid crystal device having a pattern formed therein, the method comprising changing the temperature of liquid crystal material within the device to change the refractive index of the liquid crystal material.

26. A method according to claim 25, wherein the liquid crystal material is heated by the application of a laser pulse of high intensity light.

27. A method according to claim 25 or claim 26, wherein the liquid crystal device has been manufactured using the method of any one of claims 3 to 18.

28. A liquid crystal device manufacturing apparatus comprising means for performing the steps of any one of claims 3 to 18.

29. Liquid crystal apparatus comprising means for performing the steps of any one of claims 19 to 27.

30. A liquid crystal device substantially as hereinbefore described with reference to the drawings.

31. A method of manufacturing a liquid crystal device substantially as hereinbefore described with reference to the drawings.

32. A method of operating a liquid crystal device substantially as hereinbefore described with reference to the drawings.

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INVESTOR IN PEOPLE

Application No:	GB 9930093.1	28	**Examiner:**	Geoffrey Pitchman
Claims searched:	1, 19-24		**Date of search:**	13 April 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): G2F (FCD)

Int Cl (Ed.7): G02F 1/00 1/137

Other: ONLINE: EPODOC WPI JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2161951 A	(STC)-see page 2 line 63 to page 3 line 29 especially page 2 lines 112-3	1, 19
A	WO 96/12987 A1	(PENN STATE)-see abstract	

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